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Sex prediction by metric and non-metric analysis of the hard palate and the pyriform aperture

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Background: *Analysis of the bones and bone fragments of the cranium may be a useful tool for sex diagnosis in the identification of human remains which have been exposed to adverse conditions. The object of the present study was to evaluate sex prediction through metric and non-metric analysis of the hard palate (HP) and the pyriform aperture (PA), using macerated skulls of adult individuals.*
Materials and methods: *We analysed 312 dry skulls of adult individuals of both sexes, studying the metric and non-metric characteristics of the HP and PA. The accuracy, sensitivity, specificity and positive and negative predictive values were evaluated. A binary logistic regression and a linear regression were performed. The receiver operating characteristic curve was constructed to analyse the performance of sex diagnosis. Measurements of the HP and the PA were analysed by ANOVA and Tukey's test. The SPSS v. 20.0 software was used, with a significance threshold of 5%.*
Results: *The shape of the PA presented 61.9% accuracy, 54.4% sensitivity and 65.7% specificity. The shape of the HP presented 51.5% accuracy, 65.6% sensitivity and 44.7% specificity. Only the height of the PA functioned as a good predictor of sex.*
Conclusions: *The height of the PA produced good diagnostic performance (area under curve = 0.764). The height of the PA was the most reliable indicator for sex prediction, and could be used by forensic scientists to identify sex.* (Folia Morphol 2019; 78, 1: 137–144)

Key words: pyriform aperture, hard palate, sex prediction

INTRODUCTION

Forensic anthropology is a multidisciplinary field dealing with a variety of matters, including individual identification [8]. The need to identify human remains arises both naturally and as a result of man-made disasters, when corpses are difficult to identify due to their advanced decomposition, dismemberment, mutilation or for any other reason [21]. Determining sex is a fundamental part of creating a reliable biological profile when examining skeletal remains, and is also vital in estimating age and descent [29, 30].

The cranium is considered the second most reliable bone structure for determining the sex of an adult individual [5]. Distortion of the soft tissues and bone fragmentation due to heat may make it difficult to determine sex [12]. The characteristics of the pyriform aperture (PA) offer a classic sex indicator [7]. The PA communicates the nasal cavity with the exterior; its superior limit is determined by the nasal bones and its

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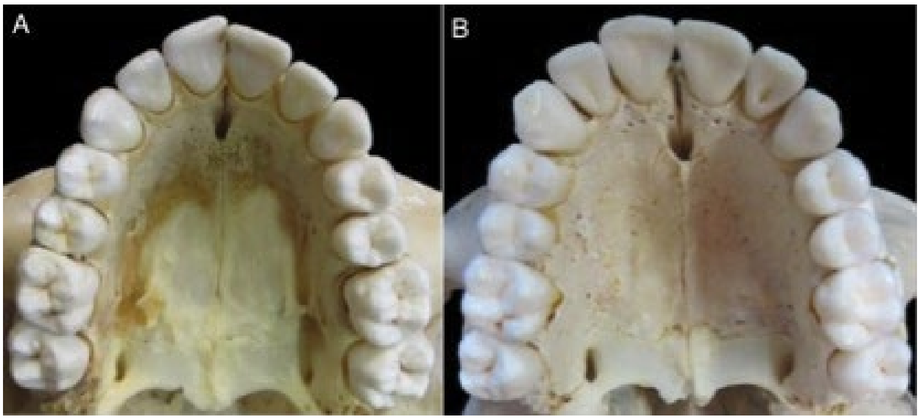

Figure 1. Non-metric characteristics of the hard palate. **A.** Female; **B.** Male.

lateral and inferior limits by the maxilla [2]. Anthropological studies suggest that the shape of the PA is influenced by congenital anatomical variations [14] and climatic factors [34], adapting to the geographical conditions in which the population lives [16]. The osseous anatomical structures located in the base region of the cranium are very strong, maintaining their vertical dimensions even when subjected to high temperatures; they are therefore ideal for sex determination [13]. The hard palate (HP) is the osseous anterior part of the palate [2], formed by the union of the palatine processes of the maxilla and horizontal plates of the palatine bones, united by a cruciform suture [28]. The HP is highly resistant, and is located in isolation in the base of the cranium. It is therefore often available for forensic analysis, even when other superficial skeletal components are damaged [13].

Both metric and non-metric (analysis of characteristics) methods are often used for determining the sex of human remains. The simplest methods are used initially, but when the remains are decomposed or incomplete and present insufficient information for diagnosis, more expensive and sophisticated complementary methods are required [21]. The object of the present study was to evaluate sex prediction through metric and non-metric analysis of the hard palate and the pyriform aperture, using macerated skulls of adult individuals.

MATERIALS AND METHODS

Samples

We analysed 312 macerated skulls of adult individuals, of both sexes, viz. 104 women and 208 men, aged between 18 and 100 years. They belonged to the Department of Morphology and Genetics, UNIFESP (Brazil). Skulls for which there was no information on sex, damaged skulls and those which presented any kind of pathology were excluded from this study. The investigators were calibrated in advance for both the metric and non-metric analyses. The investigators were blinded for the sex diagnosis, being unaware of the real identification of the skulls when they made their determination.

Analysis of non-metric characteristics

The non-metric characteristics of the HP and PA were analysed by a single investigator after prior calibration. The palate was classified as male when it was U-shaped and female when it was V-shaped (Fig. 1) [32]. The pyriform aperture was classified as male when it was high with fine margins and female when it was lower with rounded margins (Fig. 2).

Analysis of metric characteristics

The PA and HP were measured with a digital calliper.

Five measurements were taken of the HP for metric analysis: 1. Distance between the right and left greater palatine foramina (RGPF-LGPF); 2. Distance between the incisive fossa (IF) and the mid-point between the greater palatine foramina (GPF) (IF-GPF); 3. Maxillary alveolar length, i.e. the distance from the prosthion to the alveolon; 4. Maxillary alveolar amplitude, i.e. the greatest width of the alveolar process of the maxilla, measured in the vestibular faces of the maxilla at the level of the second molars; 5. Palate size, i.e. the maxillary alveolar length × maxillary alveolar amplitude / 100 [22].

Three measurements were taken of the PA for metric analysis: 1. Height of the pyriform aperture (H), measured from the inferior edge of the internasal suture to the base of the anterior nasal spine;

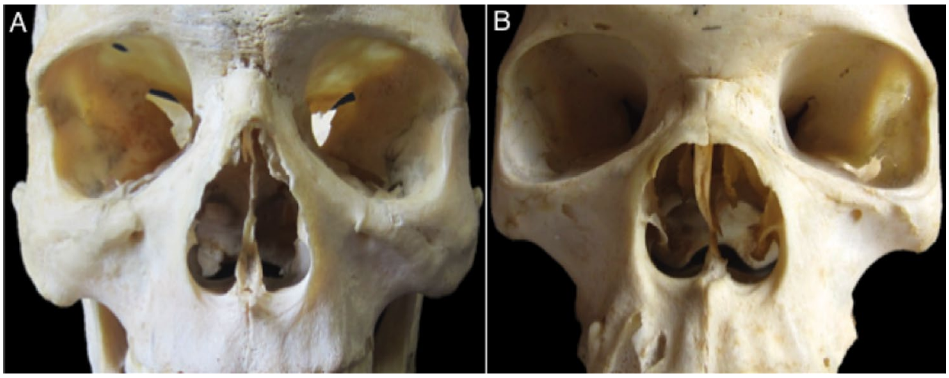

Figure 2. Non-metric characteristics of the pyriform aperture. **A.** Male; **B.** Female.

Table 1. Percentage of skulls diagnosed as male and female found to belong to men and women, respectively

Description	Sex	Woman		Man		Total		P
		N	%	N	%	N	%	
Pyriform aperture	Female	49	54%	60	34%	109	41%	0.002
	Male	41	46%	115	66%	156	59%	
Hard palate	Female	63	66%	110	55%	173	59%	0.091
	Male	33	34%	89	45%	122	41%	

N — number of skulls analysed; % — percentage

2. Superior width (SW), i.e. the distance between the extremities of the inferior margin of the nasal bones; 3. Inferior width (IW), i.e. the greatest distance between the lateral margins of the pyriform aperture.

Statistical analysis

Descriptive analysis was by means with standard deviation. The measurements were compared by ANOVA. Chi-squared test was used for the qualitative variables. A linear regression model was used to verify whether the measurements taken for the PA and HP are accurate sex predictors. A binary logistic regression was used to verify whether the morphological characteristics of the PA and HP are sex predictors. The sensitivity, specificity, accuracy and positive and negative predictive values for the non-metric variables were also analysed, and a receiver operating characteristic curve was constructed establishing a cut-off point for each measurement. The SPSS v.20.0 software was used, with a significance threshold of 5%.

RESULTS

Non-metric characteristics

By palate shape, 66% of the women's crania were classified as female, and 45% of the men's crania as male, with no statistical significance (Table 1). The sensitivity and specificity values presented a good balance, but were not very high; the negative predictive value (NPV) presented a good percentage while the positive predictive value (PPV) was low (Table 2). The binary logistic regression model for the HP was not significant (p = 0.070).

Table 2. Sensitivity and specificity for analysis of the morphological characteristics of the pyriform aperture (PA) and the hard palate (HP)

	PA	HP
Accuracy	61.9%	51.5%
Sensitivity	54.4%	65.6%
Specificity	65.7%	44.7%
PPV	45.0%	36.4%
NPV	73.7%	73.0%

PPV — positive predictive value; NPV — negative predictive value

By PA, 54% of the women's crania were classified as female, and 66% of the men's crania as male, with significant results (Table 1). There was a good balance between sensitivity and specificity, but with low values; the NPV presented a good percentage while the PPV was low (Table 2). The binary logistic regression model for the PA as a sex predictor was

Table 3. Mean values (mm), standard deviation (SD) and p value found for the hard palate by sex

Hard palate	Sex	N	Mean	SD	P
RGPF-LGPF	198	Male	30.67	2.94	0.339
	96	Female	30.31	2.76	
IF-GPF	199	Male	28.09	3.39	0.004
	96	Female	26.78	3.43	
MA length	200	Male	56.67	4.80	0.003
	96	Female	55.17	4.43	
MA amplitude	172	Male	62.41	5.21	0.007
	82	Female	60.31	4.24	
Palate size	176	Male	35.29	7.28	0.030
	84	Female	33.73	6.78	

RGPF-LGPF — distance between the left and right greater palatine foramina; IF-GPF — distance between the incisive fossa (IF) and the mid-point between the greater palatine foramina (GPF); MA — maxillary alveolar; N — number of skulls analysed

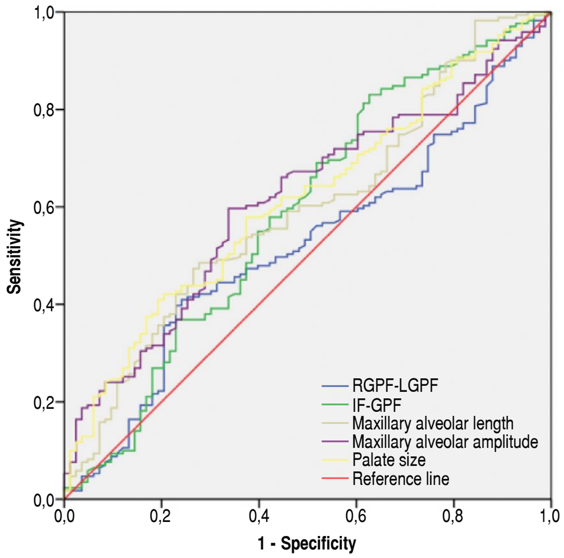

Figure 3. Receiver operating characteristic curve for the measurements taken in the hard palate; RGPF-LGPF — distance between the left and right greater palatine foramina; IF-GPF — distance between the incisive fossa (IF) and the mid-point between the greater palatine foramina.

significant, but the model was weak [$X^2(1) = 9.751$; $p = 0.002$, R^2 Nagelkerke 0.048]. The shape of the PA was a significant predictor (odds ratio = 0.442; 95% confidence interval = 0.264–0.740).

Metric characteristics

In the HP, statistical differences were found for all the distances except RGPF-LGPF. The mean values observed for men were greater than for women in all the measurements. The low coefficient of variation showed homogeneity in the results (Table 3). The RGPF-LGPF, maxillary alveolar length and palate size presented low sensitivity and good specificity. The IF-GPF distance presented high sensitivity and moderate accuracy; and the maxillary alveolar amplitude presented good sensitivity/specificity balance and moderate accuracy (Table 4). We observed that RGPF-LGPF presented low diagnostic performance, with area under the curve (AUC) very close to 0.5 (AUC = 0.537). The other distances measured for the HP presented regular diagnostic performance, with AUC of 0.604–0.617 (Fig. 3, Table 4). In the linear regression model we observed that none of the measurements for the hard palate presented good sex prediction (Table 5).

The mean values for the height of the PA found for men were significantly greater than those found for women. The superior and inferior widths presented higher mean values for males than for females, but with no statistical significance (Table 6). Only the height of the PA presented a good capacity for sex prediction; it also presented good balance between sensitivity and specificity and good accuracy (Table 7). According to the AUC analysis, the height of the PA presented good diagnostic performance (AUC = 0.764), while the other distances for the PA (superior and inferior widths) presented low diagnostic performance with the AUC very close to 0.5 (Fig. 4, Table 7).

Table 4. Analysis of the receiver operating characteristic curve for the hard palate

Hard palate	AUC	CP	Accuracy	Sensitivity	Specificity	PPV	NPV
RGPF-LGPF	0.537	31,460	53.7%	43.4%	75.0%	78.2%	39.1%
IF-GPF	0.604	25,550	67.0%	80.3%	39.6%	73.3%	49.4%
MA length	0.607	57,230	55.4%	44.9%	77.1%	80.2%	40.4%
MA amplitude	0.615	61,300	62.0%	59.9%	66.3%	78.6%	44.4%
Palate size	0.617	36,760	53.6%	41.2%	80.8%	82.4%	38.7%

RGPF-LGPF — distance between the left and right greater palatine foramina; IF-GPF — distance between the incisive fossa (IF) and the mid-point between the greater palatine foramina (GPF); MA — maxillary alveolar; AUC — area under curve; CP — cut-off point; PPV — positive predictive value; NPV — negative predictive value

Table 5. Coefficients of the logistic regression model

	Coefficient	P
Constant	2.562	0.924
RGPF-LGPF	0.010	0.884
IF-GPF	0.045	0.452
MA length	–0.390	0.428
MA amplitude	–0.373	0.405
Palate size	0.742	0.356
Height	0.382	< 0.001
Superior width	0.028	0.709
Inferior width	0.117	0.238

RGPF-LGPF — distance between the left and right greater palatine foramina; IF-GPF — distance between the incisive fossa (IF) and the mid-point between the greater palatine foramina (GPF); MA — maxillary alveolar

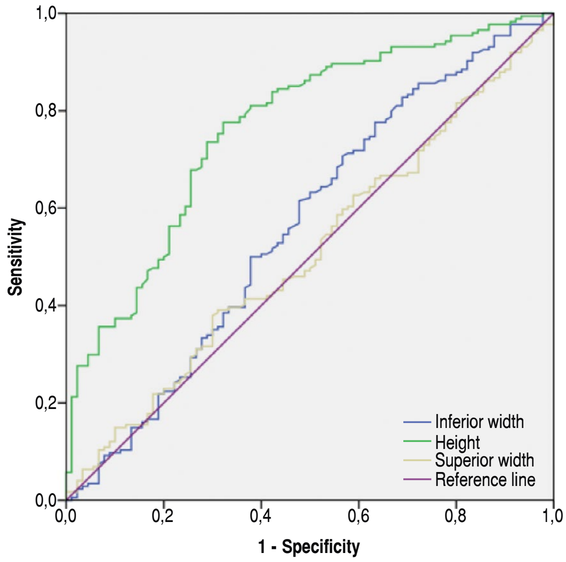

Figure 4. Receiver operating characteristic curve for the measurements taken in the pyriform aperture.

Table 6. Mean values (mm), standard deviation (SD) and p-value found for the measurements taken of the pyriform aperture, by sex

Pyriform aperture	Sex	N	Mean	SD	P
Height	Male	175	33.95	3.40	< 0.001
	Female	90	30.62	3.26	
Superior width	Male	174	16.33	2.68	0.775
	Female	90	16.23	2.45	
Inferior width	Male	174	25.05	1.95	0.064
	Female	90	24.62	2.35	

N — number of skulls analysed

The coefficient of linear regression showed that only the height is a good predictor of male sex.

Analysis of the model's quality was by percentage of concordant and discordant results; it was assessed as good with 80.6% concordant results, 19.1% discordant results and 0.3% undifferentiated. The model's quality was also analysed by Pearson's correlation (p = 0.572), the Deviance test (0.4119) and the Hosmer-Lemeshow test (p = 0.828); all showed that the model was good, with good adherence.

DISCUSSION

Determining the biological sex of skeletal remains is one of the main tasks of forensic anthropologists for victim identification [6, 11]. To do this, the forensic anthropologist must combine and compare assessments of different parts of the skeleton [6, 11, 27], since different regions of the same skeleton may present different levels of sexual expression [5].

The biomechanical load, stress and functions of each part of the body, as well as their hormone levels, can determine morphological differences in the tissues of men and women [5, 20]. In general, males are larger, with more robust facial characteristics and cranium than females [10]. Previous studies have proposed that the climate can also affect cranium shape, more specifically that the shape of the face changes under extreme climatic conditions [9]. Some authors have related the nutrition and socio-economic status of the individual with osseous morphology and levels of

Table 7. Analysis of the receiver operating characteristic curve for the pyriform aperture

Pyriform aperture	AUC	CP	Accuracy	Sensitivity	Specificity	PPV	NPV
Height	0.764	31,550	74.2%	67.8%	77.6%	61.1%	82.3%
Superior width	0.509	17,230	49.2%	39.1%	68.9%	70.8%	36.9%
Inferior width	0.562	23,730	63.6%	77.6%	36.7%	70.3%	45.8%

AUC — area under curve; CP — cut-off point; PPV — positive predictive value; NPV — negative predictive value sexual dimorphism [3]. By combining two or more of the morphological characteristics of the cranium, high levels of accuracy and precision can be achieved in determining sex [33]. The sex of the individual cannot be conclusively determined without combining more than one dimorphic sexual parameter [6, 11, 18, 27].

In the metric analysis of the pyriform aperture in this study, only the height presented sexual dimorphism, with males presenting higher mean values than females; this finding is corroborated by other authors [1, 4, 16]. The mean values found for the height of the PA in the present study were higher than found in Indians (31.16 mm for males and 26.57 mm for females) [4] and Koreans (30.1 mm for males and 28.0 mm for females) [16], and lower than reported in Egyptians (38.24 mm for males and 35.12 mm for females) [1]. The height of the PA was found to be a good predictor for determining sex, corroborating Abdelaleem et al. [1] who reported a good concordance correlation coefficient. Asghar et al. [4] analysed the inferior width of the PA in Indians and reported lower mean values than found in the present investigation (24.0 mm for males and 22.77 mm for females); Saini et al. [26], also in a population of Indians, reported values quite similar to those found in our study (25.31 mm for males and 24.97 mm for females), while Abdelaleem et al. [1] reported higher values in an Egyptian population (30.53 mm for males and 27.08 mm for females) [16]. Moreover, Abdelaleem et al. [1] and Saini et al. [26] reported that the inferior width of the PA offers 67.7–78.6% accuracy in predicting sex, similar results to those found in the present study where we report 74.2% accuracy and 0.764 AUC. In the present investigation we found no statistical differences between sexes for the inferior width of the PA, corroborating the findings of Cantín López et al. [7]; however, it should be noted that this measurement presented moderate accuracy, good sensitivity and good PPV for sex diagnosis. Nevertheless, because of its low AUC, specificity and NPV, we do not consider it a good sex predictor. We agree with Hunnargi et al. [15] who state that the conflicting results found for the inferior width of the PA may be due to the fact that precision in sex determination may vary according to the statistical method used. For the superior width of the PA, Cantín López et al. [7] found lower mean values than ours, of 13.29 mm for males and 12.75 mm for females; however like us, they found no significant difference between sexes in this dimension. Although the superior width presents good PPV, the present investigation found low accuracy and sensitivity in the sex prediction capacity of this measurement.

In our study, metric analysis of the HP showed that all the measurements present sexual differences, with higher mean values in males than in females, except for RGPF-LGPF. We observed that the RGPF-LGPF was similar to that reported in Indians, with 30.37 mm for males and 31.01 for females [18]; this absence of sexual dimorphism corroborated earlier studies [18]. The maxillary alveolar amplitudes reported for North Indians were similar to those found in our study for males (60.36 mm) and inferior to that for females (56.94 mm) [31]. In this study the maxillary alveolar amplitude presented the greatest balance between sensitivity and specificity, with good PPV and moderate accuracy. We found that the maxillary alveolar length was substantially superior to that reported for North Indians, with 51.55 mm for males and 48.81 mm for females [31], with a significant difference between the sexes. The values reported for palate size in North Indians (31.15 mm for males and 27.86 mm for females) [31] were substantially lower than those found in our study. Sumati et al. [31] reported that palate size is excellent for determining sex; our findings disagreed, since although this measurement presents sexual dimorphism and good specificity, the values for sensitivity and accuracy were low. IF-GPF was the measurement which showed the greatest accuracy and sensitivity of all the measurements analysed in this study, but with low specificity. This finding is important for forensic scientists because in some situations the alveolar margins may be pathologically deformed or fragmented by a trauma which makes cranial sexing by this anatomical structure unusable; whereas the median region of the palate, from the incisive fossa to the posterior nasal spine, is very resistant to trauma and high temperatures [18]. Although palate size is not an excellent indicator of sex, it can be used as an auxiliary resource for sexing in extreme situations when only fragments of bone are available for analysis.

The PA and the HP are important for sexual differentiation in cases when only bone fragments of the individual are accessible, since these two characteristics play a significant part in sex diagnosis [33]. In morphological analysis of the PA and the HP, we observed that the PA presents greater accuracy and better balance between sensitivity and specificity, making it a better sex predictor than the HP. The binary logistic regression showed that the model using the HP was not significant, while the model using the PA was significant but weak. Williams and Rogers [33] found greater accuracy for the shape of the PA, with 84%. In a ranking of 1–9 for combined precision plus accuracy, Williams and Rogers [33] classified the PA as the third best morphological characteristic of the cranium for sex prediction and the HP as the seventh best. We agree with Rogers [25] and Williams and Rogers [33] when they say that palate shape did not perform well for accuracy of sexual identification.

In the present investigation we carried out metric and non-metric analysis of the PA and HP in a sample of macerated skulls with information on sex. By using populations of known sex, the researcher has the advantage of being able to evaluate techniques and determine their precision and applicability [33]. It should be noted that, in our investigation, metric analysis proved a more reliable predictor of sex than non-metric analysis. The non-metric methods used to determine sex depended on visual assessment of sexually dimorphic features [23]; although these features present rapid preliminary results, they are influenced by the observer's subjectivity [19], and must be carried out by an experienced observer for precise analysis [21]. Metric methods are based on the basic principle of variations in physical dimensions between males and females. Different statistical methods are used to derive models/equations which can be used for sexing [17, 24]. In this study, sex prediction by analysis of the morphological characteristics of the PA was better than by measuring the HP, with greater accuracy and sensitivity/specificity ratio. Metric analysis showed that both structures present sexual dimorphism; however, the height of the pyriform aperture was the measurement which showed the greatest accuracy and the best sensitivity/specificity ratio for diagnosing sex, and was the best sex predictor of the measurements evaluated in this study.

CONCLUSIONS

Non-metric analysis of the PA presented better accuracy and sensitivity/specificity ratio than HP, and can be used in association with other parameters as an additional tool for sex determination, especially when only bone fragments are available for sexing. Metric analysis of the HP showed sexual dimorphism in this structure; however, the height of the PA was the most reliable indicator for sex prediction, and could be used by forensic scientists to identify sex.

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